

ORIGINAL RESEARCH

Effect of surface pretreatment on the shear bond strength of glass ionomer-based and giomer fissure sealants: an *in vitro* study

Berkay Akay^{1,*}, Senem Selvi Kuvvetli¹

¹Department of Pediatric Dentistry,
Faculty of Dentistry, Yeditepe University,
34728 Istanbul, Türkiye

***Correspondence**berkay.akay@yeditepe.edu.tr

(Berkay Akay)

Abstract

Background: While phosphoric acid etching is standard for resin-based sealants, its effect on glass ionomer and giomer sealants remains less explored. This *in vitro* study evaluated the shear bond strength (SBS) of various fissure sealant materials applied to bovine enamel using different surface conditioning methods (phosphoric acid, conditioner, or no pretreatment). **Methods:** 100 bovine incisors were prepared and divided into four material groups: Fuji TRIAGE® (FT; n = 30), Riva Protect® (RP; n = 30), BeautiSealant® (BT; n = 30), and Helioseal F Plus® (HF; control, n = 10). Specimens were assigned to subgroups based on pretreatment: 37% phosphoric acid, material-specific conditioner, or no pretreatment. SBS testing was performed according to the International Organization for Standardization (ISO) 29022 standards. Bonding failure types were classified according to the Adhesive Remnant Index under 25× magnification using a ZEISS OPMI® pico S100 microscope. Data were analyzed using one-way analysis of variance (ANOVA), chi-squared, and Bonferroni tests ($p < 0.05$). **Results:** Significant differences were observed ($p < 0.001$). The control group (HF) demonstrated the highest SBS (15.21 ± 1.15 MPa). Among the alternative materials, BT pretreated with phosphoric acid (13.18 ± 2.96 MPa) showed significantly higher SBS than with a self-etching primer (10.23 ± 1.85 MPa). Furthermore, the BT exhibited significantly higher bond strength values than both glass ionomer-based sealants (FT and RP) across all conditioning protocols. Adhesive failures were predominant in groups with lower bond strengths. **Conclusions:** Resin-based fissure sealant applied with phosphoric acid etching demonstrated the highest SBS values among all tested groups. However, the giomer-based sealant exhibited superior bonding performance compared with the glass ionomer-based sealants. Additionally, phosphoric acid etching significantly enhanced the adhesion of the giomer material, suggesting that surface conditioning plays a crucial role in maximizing the retention of bioactive sealants.

Keywords

Fissure sealants; Shear bond strength; Giomer; Glass ionomer; Phosphoric acid etch; Pretreatment methods

1. Introduction

Dental caries is the most common chronic disease of childhood despite being largely preventable [1]. There are approximately 64.6 million incidences of permanent dentition and an additional 62.9 million incidences of primary dentition [2]. Untreated dental caries can lead to discomfort, infection, and oral dysfunction, adversely impacting children's general health and oral health-related quality of life [3].

The occlusal surfaces, particularly pits and fissures, are disproportionately susceptible to caries formation due to their morphological complexity. Despite comprising only 12.5% of all tooth surfaces, these areas favor plaque accumulation and food retention, contributing to over two-thirds of the to-

tal caries incidence in children. The first permanent molars exhibit particularly elevated susceptibility in the initial years following eruption [4]. Since demineralization often begins shortly after eruption, pit and fissure sealants serve as a critical preventive measure. These materials protect the vulnerable occlusal surfaces, especially of the first permanent molars, by creating a physical barrier over the anatomical irregularities that are otherwise difficult to clean [4].

Fissure sealants are effective in preventing the progression of early carious lesions when applied to these vulnerable surfaces. Minimally invasive applications, such as fissure sealants, are recommended to provide prevention for children and adolescents at high caries risk. Pit and fissure sealants are expected to adhere to the enamel surface in the applica-

tion area and maintain their seal for a long period of time to prevent caries. The retention of sealants extends their protective barrier, hence reducing the risk of dental caries. The type and composition of the materials, viscosity, and bonding mechanisms influence the retention of pit and fissure sealants [5].

The effectiveness of these materials depends primarily on their retention and integrity, and additional benefits may be achieved if the materials also release fluoride. Conventional resin-based sealants (RBS) require prior application of phosphoric acid to enhance bonding; however, this process may also lead to excessive enamel demineralization [6]. In contrast, glass ionomer-based sealants, which can chemically adhere to dental hard tissues and have fluoride release potential, may serve as effective remineralizing agents when applied to the enamel surface [7, 8].

Another class of materials, giomer sealants, incorporates Surface Pre-Reacted Glass-ionomer (S-PRG) filler technology within a resin matrix. These materials aim to combine the fluoride-releasing and recharging properties of glass ionomers with the mechanical strength and aesthetics of resin composites [9].

The incorporation of bonding agents beneath resin-based sealants has been explored to enhance sealant retention and reduce microleakage. Studies indicate that using a bonding agent can improve the sealant's adhesion to enamel, particularly in situations when adequate isolation is achieved. A study demonstrated that bonding agent application prior to the sealant significantly reduced microleakage compared with the conventional technique without a bonding agent. This approach was stated to be especially beneficial for fully erupted teeth, where moisture control is more manageable, thereby enhancing the longevity of the sealant [10].

Conversely, glass ionomer sealants (GIS) are often preferred in clinical scenarios where moisture control is compromised, with partially erupted molars and/or uncooperative pediatric patients. GIS materials chemically bond to the tooth structure and release fluoride, offering caries-preventive benefits even when retention is suboptimal. A long-term study reported that although the retention rate of GIS decreased over time, a significant proportion of occlusal surfaces remained caries-free after 13 years. This information proves the material's efficacy in caries prevention, particularly in high-risk populations [11].

From a clinical standpoint, the selection between resin-based and glass-ionomer-based sealants should be guided by the tooth's eruption phase and the feasibility of moisture control. Employing bonding agents before RBS can enhance sealant performance on fully erupted teeth, while GIS serves as a viable alternative in situations where isolation is difficult. Understanding the properties and appropriate applications of these materials is crucial for optimizing preventive strategies in dental practice [12].

In restorative dentistry, various surface treatments have been investigated to enhance the bond strength of glass ionomer cements (GIC) [13]. Phosphoric acid etching, in particular, has been shown to improve the adhesion of glass ionomer cements to dentin by effectively removing the smear layer and promoting micromechanical retention. An *in vitro* study conducted by Di Nicoló *et al.* [14] (2007) evaluated the effect

of dentin conditioning with 35% phosphoric acid prior to the application of glass ionomer cements. They determined a higher shear bond strength (SBS) compared with traditional conditioning methods [14]. Although these findings primarily relate to dentin, the principle of maximizing micromechanical retention via acid etching is even more pertinent to enamel bonding, where the creation of a distinct etching pattern is essential for sealant penetration.

Recent studies have continued to explore optimum bonding protocols for bioactive materials. For instance, Zavare *et al.* [15] (2023) highlighted the material-dependent nature of adhesion when comparing giomer and resin-modified glass ionomers. However, while the benefits of phosphoric acid pretreatment have been explored in restorative applications, there is a lack of research examining its effects on the bond strength of glass ionomer-based fissure sealants and giomer fissure sealants. While clinical retention is the ultimate indicator of success, *in vitro* SBS testing serves as a critical preliminary assessment to screen different surface conditioning protocols before clinical application. This gap in the literature highlights the need for further studies to determine whether similar conditioning protocols could enhance the performance of these materials when used as sealants.

To the best of our knowledge, there is limited literature evaluating the effect of phosphoric acid application before glass ionomer-based and giomer fissure sealants on their bond strength. Therefore, this study aims to evaluate the SBS of various fissure sealant materials applied with different conditioning methods (phosphoric acid, conditioner, and no pretreatment) under *in vitro* conditions. The null hypothesis tested was that different surface conditioning methods would not affect the SBS of the tested fissure sealant materials.

2. Materials and methods

2.1 Study design

An *in vitro* experimental design was used in the present study to evaluate the SBS of different fissure sealant materials applied with various conditioning methods. A total of 100 bovine teeth were selected as substitutes for human enamel due to their comparable structural properties. The study protocol was reviewed by the Yeditepe University Faculty of Dentistry Scientific Review Board (#609) and the Yeditepe University Local Ethics Committee for Animal Experiments (YULECAE) during its meeting on 21 May 2024. Based on Article 8 of the "Regulation on the Working Procedures and Principles of Animal Experiments Ethics Committees", which states that procedures using dead animal tissue, slaughterhouse materials, or fetal waste fall outside the scope of ethical review, it was determined that this research did not require formal ethical approval. This official assessment was confirmed and documented by YULECAE. The study was, therefore, conducted under the assurance of compliance with institutional and national ethical guidelines for *in vitro* research using non-living animal-derived specimens. The experimental procedures were conducted between 22 April and 30 May 2025. To minimize selection bias, the teeth were randomly allocated to the study groups.

2.2 Materials used in the study

In this experiment, four different commercially available fissure sealant materials were used. Fuji TRIAGE® (#250311 GC Corp., Tokyo, Japan) is a glass ionomer sealant and surface protectant. Riva Protect® (#1212217A, SDI Limited, Bayswater, Australia) is a low-viscosity glass-ionomer-based sealant. BeautiSealant® (#032383, Shofu Inc., Kyoto, Japan) is a fluoride-recharging pit-and-fissure sealant formulated with Surface Pre-Reacted Glass (S-PRG) technology. Helioseal F Plus® (#Z07J2X, Ivoclar, Zurich, ZH, Switzerland) is a light-curing, resin-based fissure sealant that possesses fluoride-releasing properties. In the study groups that required primer pretreatment, all applications were made according to the manufacturer's instructions (Table 1).

2.3 Determination of study groups and sample size

A power analysis was conducted using G*Power 3.1 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, NRW,

Germany) to determine the minimum sample size based on an effect size of 0.44 derived from the results of similar previous *in vitro* studies [16, 17], using an alpha error probability of 0.05 and a power of 0.80. The analysis indicated that at least nine samples per group were required. However, to ensure robust statistical analysis and account for potential experimental variability, the sample size was increased to 10 specimens per group (Table 2).

2.4 Preparation of the specimens

2.4.1 Storage and preparation of the tooth surfaces

One hundred bovine incisors were used in the study, chosen for their similarity to human enamel. The extracted teeth were stored in distilled water, and before testing, the samples were thoroughly rinsed with distilled water to remove any residue.

The crowns of the teeth were separated from their roots with the help of a precision saw (BUEHLER IsoMet® 1000, Buehler, Lake Bluff, IL, USA) and a diamond separator

TABLE 1. Materials used in the study, along with the manufacturer, content, and LOT numbers.

Name of Product	Manufacturer	Product Information	LOT Numbers
Fuji TRIAGE®	GC Corp. Japan	Glass ionomer-based sealant and surface protectant.	#2503111
Riva Protect®	SDI Limited Australia	Low viscosity glass ionomer-based sealant.	#1212217A
BeautiSealant®	Shofu Inc. Japan	Fluoride recharging, pit and fissure sealant filled with Surface Pre-Reacted Glass (S-PRG).	#032383
Helioseal F Plus®	Ivoclar Switzerland	Light-curing, composite resin fissure sealant with fluoride-releasing properties.	#Z07J2X

TABLE 2. The material groups used in the study and the subgroups, divided according to the pretreatment method (n = 10 per subgroup; total n = 100).

Material Groups	Subgroups According to the Pretreatment Methods
Fuji TRIAGE (GC®)	(FTA): Pretreatment with phosphoric acid (FTC): Pretreatment with own conditioner (FTN): No pretreatment
Riva Protect (SDI®)	(RPA): Pretreatment with phosphoric acid (RPC): Pretreatment with own conditioner (RPN): No pretreatment
BeautiSealant (Shofu®)	(BSA): Pretreatment with phosphoric acid (BSC): Pretreatment with own conditioner (BSN): No pretreatment
Helioseal F Plus (Ivoclar®)	(HF): Pretreatment with phosphoric acid (Control Group)

FTA: Fuji TRIAGE + Acid; FTC: Fuji TRIAGE + Conditioner; FTN: Fuji TRIAGE (No pretreatment); RPA: Riva Protect + Acid; RPC: Riva Protect + Conditioner; RPN: Riva Protect (No pretreatment); BSA: BeautiSealant + Acid; BSC: BeautiSealant + Conditioner; BSN: BeautiSealant (No pretreatment); HF: Helioseal F Plus (Control).

(A7354 Medium Grain 200, 0.17 mm Acurata®) under water cooling (Fig. 1). The mesial, distal, and incisal edges of the teeth were also separated from the tooth using a diamond separator with water cooling. Samples for the bond strength study were placed in an acrylic resin block to facilitate handling during testing. The specimens were then randomly assigned to four main material groups ($n = 30$ for experimental groups, $n = 10$ for control). Afterwards, the buccal surface of the tooth was polished with 600-, 800-, and 1200-grit sandpaper (English Abrasives and Chemicals Ltd., London) under running water. The flattened enamel surface was cleaned with ultrasonic cleaning to remove organic debris.

2.4.2 Application of fissure sealants to tooth surfaces

The specimens in the FTA (Fuji TRIAGE + Acid), RPA (Riva Protect + Acid), BSA (BeautiSealant + Acid), and HF (Helioclear F Plus (Control)) groups were pretreated with 37%

phosphoric acid for 30 seconds and rinsed with water. To ensure standardization, the same acid etchant was used across all applicable groups. After air-drying, the corresponding sealant was applied using a silicon mold with a 1.5 mm radius and 2 mm height. The BSA and HF groups were photo-polymerized using a LED (light-emitting diode) curing unit (Bluephase® N G4, Ivoclar, Schaan, Liechtenstein) (1200 mW/cm^2) for 20 seconds in accordance with the manufacturers' instructions.

The specimens in the FTC (Fuji TRIAGE + Conditioner) group were pretreated with GC Cavity Conditioner (GC Corp. Japan) for 10 seconds and rinsed with water. In the RPC (Riva Protect + Conditioner) group, specimens were pretreated with SDI Riva Conditioner (SDI Limited Australia) for 10 seconds and rinsed with water. For the BSC (BeautiSealant + Conditioner) group, specimens were pretreated with BeautiSealant Primer (Shofu Inc., Japan) for 5 seconds and dried. All conditioning and priming steps were performed in strict adherence to the respective manufacturers' instructions.



FIGURE 1. The separation of the teeth from their roots using a precision saw (BUEHLER IsoMet® 1000) and a diamond separator (A7354 Medium Grain 200, 0.17 mm Acurata®) under water cooling.

After air-drying, the inner lesion area, with a 1.5 mm radius, within the pretreated area was filled with the corresponding sealant using a 2 mm height silicon mold. The specimens in the BSC group were photo polymerized using a LED curing unit (Bluephase® N G4 Ivoclar Liechtenstein) (1200 mW/cm^2) for 20 seconds. Fuji TRIAGE and Riva Protect are chemically cured (self-cure) glass ionomer materials; therefore, no light curing was applied to the FTN (Fuji TRIAGE (No pretreatment)) and RPN (Riva Protect (No pretreatment)) groups, following the manufacturers' protocols.

In the FTN, RPN, and BSN (BeutiSealant (No pretreatment)) groups, no pretreatments were applied to the tooth surfaces. After preparation, the area of 1.5 mm radius was filled using the corresponding sealant using a 2 mm height silicon mold. The BSN group was photo-polymerized using a LED curing unit (Bluephase® N G4 Ivoclar Liechtenstein) (1200 mW/cm^2) for 20 seconds.

The experimental design and distribution of the study groups are illustrated in the flowchart shown in Fig. 2.

2.5 Testing of shear bond strength

Prior to testing, all specimens were stored in distilled water at 37°C for 24 hours to simulate the immediate oral environment. SBS testing was performed using a universal testing machine (Instron® 3345, Instron Corp., Norwood, MA, USA) equipped with a 500 N load cell. Each specimen was

mounted in a custom jig to ensure stable positioning and precise force application. A chisel-shaped loading head was aligned perpendicular to the enamel-sealant interface, and a shear load was applied at a crosshead speed of 1 mm/min until failure occurred. To reduce potential bias, the operator performing the SBS testing was blinded to the specific study groups. The SBS was calculated by dividing this force by the bonded surface area (mm^2), yielding values in megapascals (MPa). This method ensured standardized loading conditions and minimized variability across samples (Fig. 3).

2.6 Assessment of bonding failure categories

The mode of bonding failure was identified by the remaining sealant on the enamel surface, which was used to determine the bond failure location according to the Adhesive Remnant Index (ARI). The failure modes were categorized as “adhesive failure”, “cohesive failure”, or “mixed failure”. Adhesive failure was indicated by fractures at the contact between the enamel and the bonding agent or sealant. Cohesive failure was indicated when failure occurred primarily within the sealant. Mixed failure was observed when a portion of the sealant adhered to the enamel. Bonding failure categories were classified through examination under $25\times$ magnification using a ZEISS OPMI® pico S100 microscope (Fig. 4).

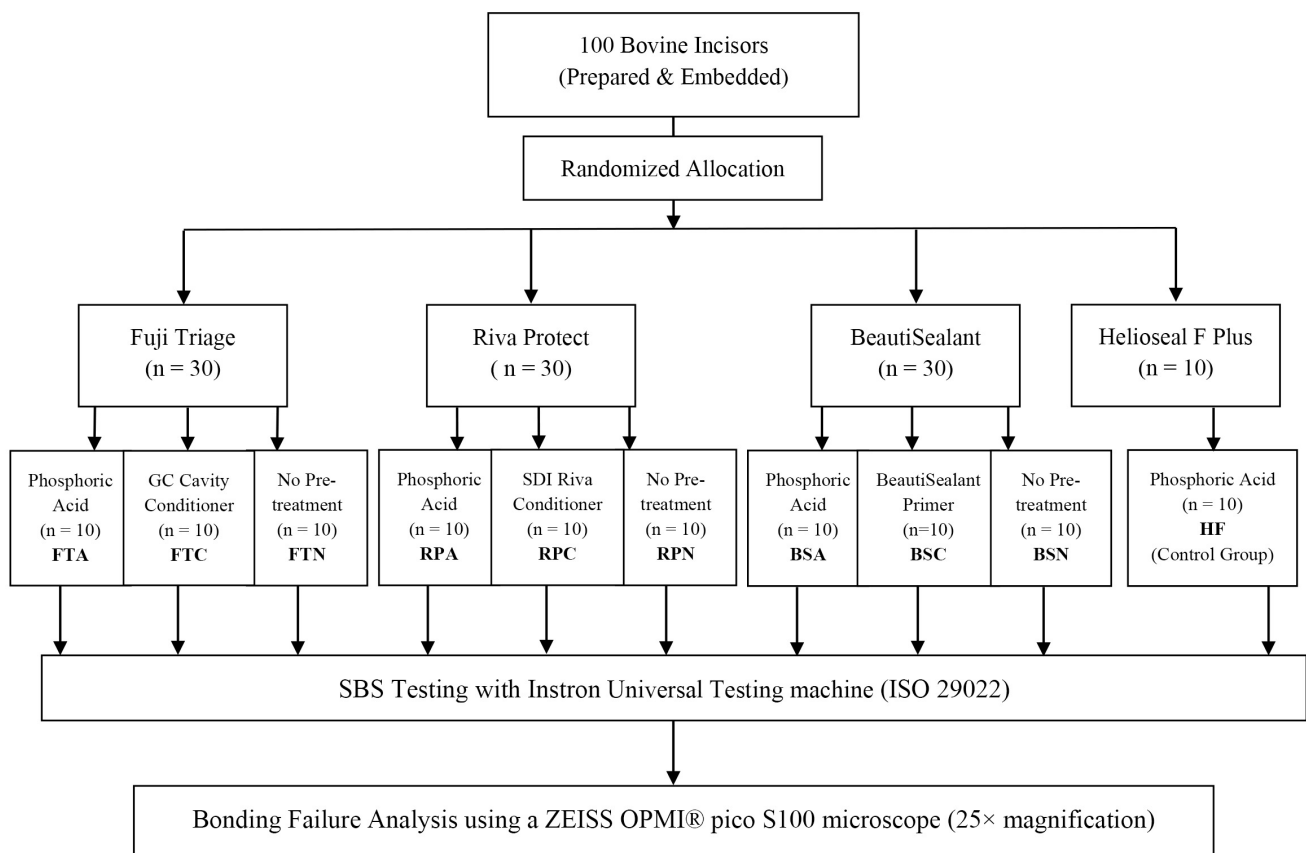


FIGURE 2. Flowchart of the experimental design and distribution of the study groups. FTA: Fuji TRIAGE + Acid; FTC: Fuji TRIAGE + Conditioner; FTN: Fuji TRIAGE (No pretreatment); RPA: Riva Protect + Acid; RPC: Riva Protect + Conditioner; RPN: Riva Protect (No pretreatment); BSA: BeutiSealant + Acid; BSC: BeutiSealant + Conditioner; BSN: BeutiSealant (No pretreatment); HF: Heliocel F Plus (Control); SBS: Shear Bond Strength; ISO: International Organization for Standardization.

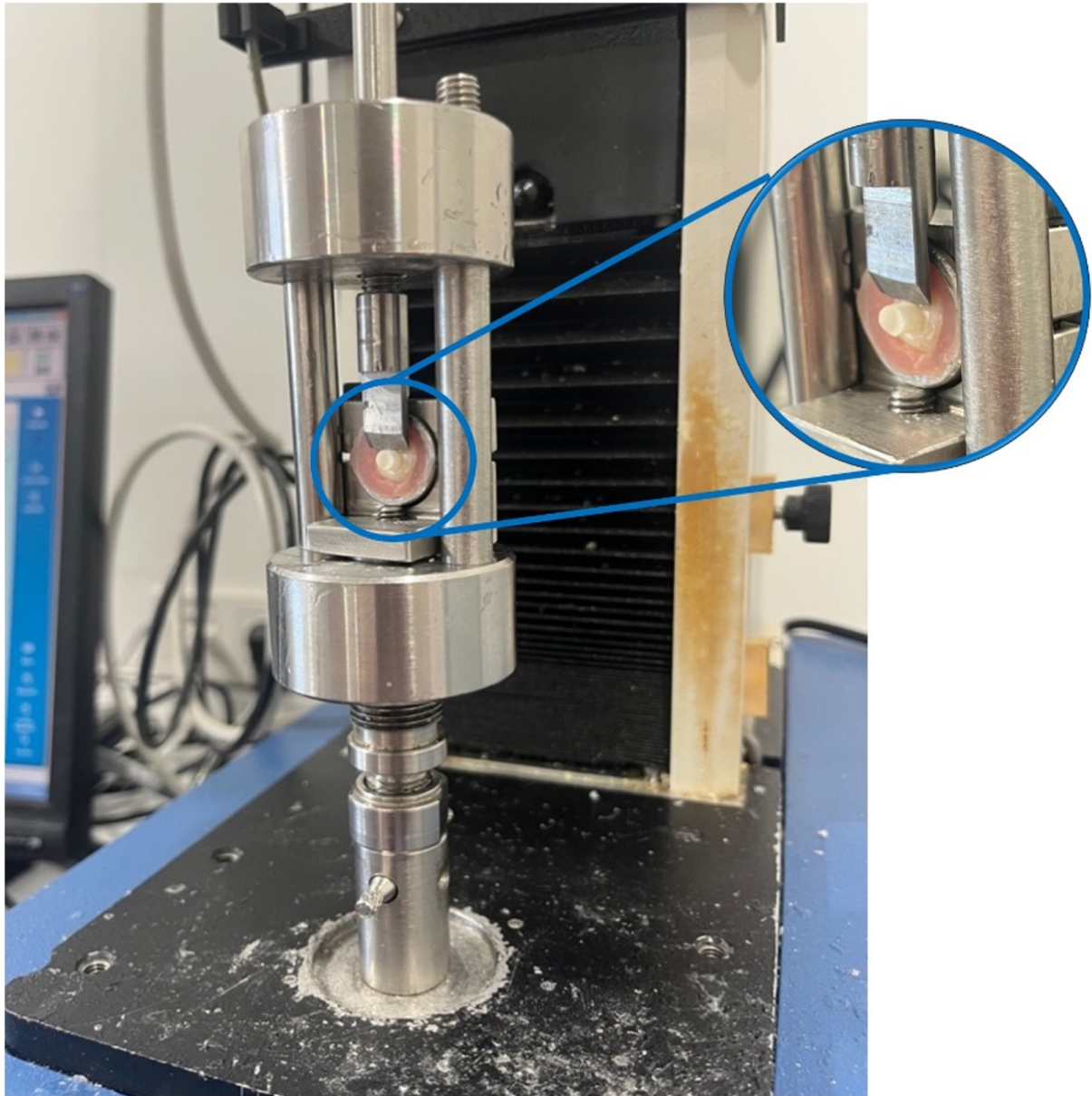


FIGURE 3. Shear bond strength (SBS) test setup performed using an Instron universal testing machine (Instron® 3345, Instron Corp., USA) equipped with a chisel-shaped loading head aligned perpendicular to the enamel-sealant interface.

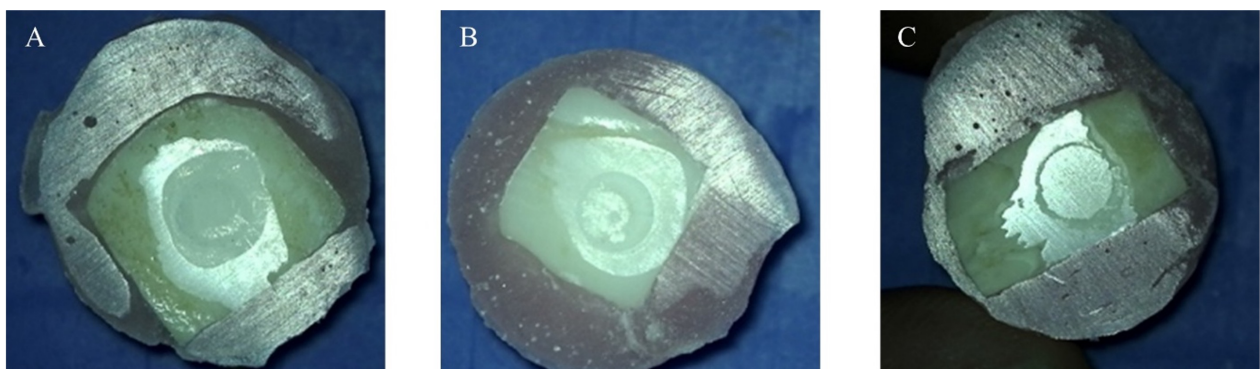


FIGURE 4. Representative images of bonding failure modes captured with a Zeiss OPMI Pico S100 microscope at magnification of 25 \times . (A) Cohesive failure (>80% of remaining sealant); (B) Mixed failure (20–80% of the remaining sealant); and (C) Adhesive Failure (<20% of remaining sealant).

2.7 Statistical analysis

The normality of the data was assessed using the Shapiro-Wilk test. One-way analysis of variance (ANOVA) and Bonferroni *post-hoc* tests were used for group comparisons of SBS (MPa) values. The Fisher exact and chi-squared tests were used to compare bonding failure categories. Statistical significance was defined as $p < 0.05$, with a 95% confidence interval (CI) reported.

3. Results

3.1 Results of the shear bond strength tests

The mean and standard deviation of SBS values in megapascals (MPa) obtained in the subgroups according to the pretreatment methods, and the results of the intragroup and intergroup comparisons are given in Table 3. According to the one-way ANOVA test, the differences in SBS values across all pretreatment methods were statistically significant ($p < 0.001$). According to the Bonferroni *post-hoc* test, the comparison of the subgroups within the phosphoric acid application showed that the HF group values were significantly higher than those of the FTA, RPA, and BSA groups. It was also determined that the BSA values were higher than those of the FTA and RPA groups. The BSC subgroup showed significantly higher values than the FTC and RPC subgroups, which belonged to their respective conditioners. Finally, the comparison between no pretreatment specimens showed that the BSN subgroup values were significantly higher than those of the RPN and FTN subgroups.

Table 4 presents the mean and standard deviation of SBS

values (MPa) for the subgroups by material group, along with the results of intragroup and intergroup comparisons. According to the one-way ANOVA test, the differences in SBS values across all material groups were statistically significant ($p < 0.001$). The intergroup comparisons with the Bonferroni *post-hoc* test showed that the FTA and FTC subgroups had significantly higher values than the FTN subgroup in the Fuji TRIAGE (GC®) material group. Similarly, in the Riva Protect (SDI®) material group, the RPA subgroup exhibited significantly higher values than the RPC and RPN subgroups, and the RPC subgroup also had higher values than the RPN subgroup. Also, among BeautiSealant (Shofu®) subgroups, the BSA subgroup showed significantly higher SBS than the BSC and BSN subgroups, and the BSC subgroup values were higher than those of the BSN subgroup.

3.2 Results of bonding failure categories

A statistically significant difference in the number and percentage of failures was found between subgroups in the no pretreatment group; in other words, failure types were not similar across all subgroups ($p < 0.05$). It was observed that, whereas the percentage of adhesive failures was highest, mixed failures were identified at the lowest level in the RPN group (52.9%, 7.7%, respectively) (Table 5).

A statistically significant difference was found between the number and percentage of failures of the subgroups in the Riva Protect (SDI®) group. In other words, failure types were not similar across all subgroups ($p < 0.05$). It was determined that 56.3% of adhesive fractures occurred in the RPN group, while 61.5% of mixed fractures and 100% of cohesive fractures were observed in the RPA group (Table 6).

TABLE 3. Mean and standard deviation values for SBS in the subgroups according to the pretreatment method, along with intragroup and intergroup comparisons.

Shear Bond Strength Comparison (MPa) Pretreatment Method	Subgroups	Mean \pm SD	<i>p</i> -value	<i>Post-hoc</i>
Phosphoric Acid	HF	15.21 \pm 1.15 ^a	<0.001*	a > b, c c > b
	FTA	2.44 \pm 0.65 ^b		
	RPA	2.67 \pm 0.37 ^b		
	BSA	13.18 \pm 2.96 ^c		
Conditioner	FTC	2.31 \pm 0.43 ^d	<0.001*	e > d
	RPC	2.27 \pm 0.29 ^d		
	BSC	10.23 \pm 1.85 ^e		
No Pretreatment	FTN	0.72 \pm 0.13 ^f	<0.001*	g > f
	RPN	0.81 \pm 0.22 ^f		
	BSN	2.28 \pm 0.61 ^g		

* $p < 0.05$ according to the one-way ANOVA test.

Different superscript lowercase letters in the same column indicate statistically significant differences between groups ($p < 0.05$) according to the Bonferroni *post-hoc* test; identical letters indicate no significant difference. HF: Heliocel F Plus (Control); FTA: Fuji TRIAGE + Acid; FTC: Fuji TRIAGE + Conditioner; FTN: Fuji TRIAGE (No pretreatment); RPA: Riva Protect + Acid; RPC: Riva Protect + Conditioner; RPN: Riva Protect (No pretreatment); BSA: BeautiSealant + Acid; BSC: BeautiSealant + Conditioner; BSN: BeautiSealant (No pretreatment); MPa: Megapascal; SD: Standard Deviation.

TABLE 4. Mean and standard deviation values for shear bond strength in the subgroups by material, with intragroup and intergroup comparisons.

Shear Bond Strength Comparison (MPa) Materials	Subgroups	Mean \pm SD	<i>p</i> -value	Post-hoc
Fuji TRIAGE (GC®)	FTA	2.44 \pm 0.65 ^a	<0.001*	a > b
	FTC	2.31 \pm 0.43 ^a		
	FTN	0.72 \pm 0.13 ^b		
Riva Protect (SDI®)	RPA	2.67 \pm 0.37 ^c	<0.001*	c > d, e d > e
	RPC	2.27 \pm 0.29 ^d		
	RPN	0.81 \pm 0.22 ^e		
BeautiSealant (Shofu®)	BSA	13.18 \pm 2.96 ^f	<0.001*	f > g, h g > h
	BSC	10.23 \pm 1.85 ^g		
	BSN	2.28 \pm 0.61 ^h		

**p* < 0.05 according to the one-way ANOVA test.

Different superscript lowercase letters in the same column indicate statistically significant differences between groups (*p* < 0.05) according to the Bonferroni post-hoc test; identical letters indicate no significant difference. HF: Helioclear F Plus (Control); FTA: Fuji TRIAGE + Acid; FTC: Fuji TRIAGE + Conditioner; FTN: Fuji TRIAGE (No pretreatment); RPA: Riva Protect + Acid; RPC: Riva Protect + Conditioner; RPN: Riva Protect (No pretreatment); BSA: BeautiSealant + Acid; BSC: BeautiSealant + Conditioner; BSN: BeautiSealant (No pretreatment); MPa: Megapascal; SD: Standard Deviation.

TABLE 5. Number, percentage, and comparison of failure types observed after shear bond.

	Failure Type						<i>p</i> -value
	Adhesive Failures		Mixed Failures		Cohesive Failures		
	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	
Phosphoric Acid							0.057
HF	2	15.4	8	32.0	0	0.0	
FTA	3	23.1	6	24.0	1	50.0	
RPA	1	7.7	8	32.0	1	50.0	
BSA	7	53.8	3	12.0	0	0.0	0.274
Conditioner							
FTC	3	25.0	6	42.9	1	25.0	
RPC	6	50.0	4	28.6	0	0.0	
BSC	3	25.0	4	28.6	3	75.0	0.046*
No Pretreatment							
FTN	4	23.5	6	46.2	0	0.0	
RPN	9	52.9	1	7.7	0	0.0	
BSN	4	23.5	6	46.2	0	0.0	

Strength testing in the subgroups according to the pretreatment method.

**p* < 0.05 according to the χ^2 test.

HF: Helioclear F Plus (Control); FTA: Fuji TRIAGE + Acid; FTC: Fuji TRIAGE + Conditioner; FTN: Fuji TRIAGE (No pretreatment); RPA: Riva Protect + Acid; RPC: Riva Protect + Conditioner; RPN: Riva Protect (No pretreatment); BSA: BeautiSealant + Acid; BSC: BeautiSealant + Conditioner; BSN: BeautiSealant (No pretreatment).

TABLE 6. Number, percentage, and comparison of failure types observed after shear bond strength testing across the subgroups by material.

	Failure Type						<i>p</i> -value
	Adhesive Failure		Mixed Failure		Cohesive Failure		
	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	
Fuji TRIAGE (GC®)							
FTA	3	30.0	6	33.3	1	50.0	1.000
FTC	3	30.0	6	33.3	1	50.0	
FTN	4	40.0	6	33.3	0	0.0	
Riva Protect (SDI®)							
RPA	1	6.3	8	61.5	1	100.0	0.003*
RPC	6	37.5	4	30.8	0	0.0	
RPN	9	56.3	1	7.7	0	0.0	
BeautiSealant (Shofu®)							
BSA	7	50.0	3	23.1	0	0.0	0.104
BSC	3	21.4	4	30.8	3	100.0	
BSN	4	28.6	6	46.2	0	0.0	

* $p < 0.05$ according to the χ^2 test.

HF: Helioseal F Plus (Control); FTA: Fuji TRIAGE + Acid; FTC: Fuji TRIAGE + Conditioner; FTN: Fuji TRIAGE (No pretreatment); RPA: Riva Protect + Acid; RPC: Riva Protect + Conditioner; RPN: Riva Protect (No pretreatment); BSA: BeautiSealant + Acid; BSC: BeautiSealant + Conditioner; BSN: BeautiSealant (No pretreatment).

4. Discussion

The present study evaluated the effect of different surface treatment methods, specifically phosphoric acid etching, polyacrylic acid conditioning, and no surface preparation, on the SBS of glass ionomer-based and giomer fissure sealants. Based on the statistical analysis, significant differences in bond strength were observed among the experimental groups; therefore, the tested null hypothesis was rejected. This investigation addresses a notable gap in the existing literature. While several studies have investigated the effect of surface treatments on the bond strength of glass ionomer cements in restorative procedures, limited attention has been given to their influence when these materials are used as fissure sealants. To our knowledge, this is one of the first studies to explore the potential benefits of phosphoric acid etching on the adhesion performance of these specific sealant materials.

4.1 Effect of surface conditioning and material type

The methodology of this study was carefully designed to evaluate the SBS of glass ionomer-based and giomer fissure sealants applied with various surface conditioning methods (phosphoric acid etching, polyacrylic acid conditioner, and no preparation) and to compare the findings with those of conventional resin-based sealants applied after phosphoric acid etching. This approach was selected in response to increasing interest in

the clinical performance of newer bioactive sealant materials, particularly those containing surface-pre-reacted glass-ionomer (S-PRG) fillers. For example, Ogawa *et al.* [9] (2021) demonstrated that S-PRG-containing sealants significantly inhibited enamel demineralization around the sealant margins, highlighting the potential of these materials not only to provide physical sealing, but also to enhance preventive effects through ion release.

Furthermore, recent systematic reviews and clinical trials have underscored the versatility of high-viscosity glass ionomer cements in challenging clinical scenarios. Specifically, their hydrophilic nature renders them superior in treating partially erupted molars where effective moisture control is often unachievable [17]. Moreover, despite established concerns about retention rates relative to resin-based alternatives, contemporary studies suggest that the sustained fluoride release and chemical adhesion of GICs provide a caries-preventive effect comparable to that of resin-based alternatives [18].

The relatively higher SBS values observed for the giomer-based sealant (BeautiSealant), particularly when combined with phosphoric acid etching (BSA), underscore the evolving role of bioactive materials. Although phosphoric acid etching has traditionally been associated with resin-based sealants, our results indicate that it significantly maximizes the adhesion of giomer-based materials compared with their specific self-etching primers. This aligns with findings by Poggio *et al.* [19] (2021), who reported that phosphoric acid enhances microme-

chanical interlocking even in materials designed for chemical bonding.

Regarding glass ionomer sealants, our findings suggest that phosphoric acid may offer superior surface adhesion compared with conventional polyacrylic acid conditioning. This aligns with previous findings by Di Nicoló *et al.* [14] (2007) and Sidhu & Nicholson [20] (2014), who emphasized that phosphoric acid pretreatment facilitates better smear layer removal and improves micromechanical bonding. However, it is important to acknowledge a potential drawback: aggressive etching of glass ionomer cements may theoretically interfere with their chemical bonding mechanism by demineralizing the hydroxyapatite necessary for ionic exchange. Nevertheless, in the present study, the gain in micromechanical retention provided by phosphoric acid appeared to outweigh the potential loss of chemical adhesion.

4.2 Clinical implications

From a clinical standpoint, the comparison of bond strength values provides guidance for material selection. The findings of the SBS test indicated that the HF, BSA, and BSC groups demonstrated bond strength values generally considered acceptable for clinical use. These results are consistent with the minimum threshold of 6–8 MPa historically established by Reynolds (1975) [21]. While ISO standards define the testing methodology rather than specific performance thresholds, the “acceptability” of these values is supported by their alignment with effective enamel adhesion ranges reported in current literature. Although the bonding values observed in the remaining experimental groups were lower than these thresholds, they should be interpreted in the context of the geometric discrepancies between the standardized test protocols and the clinical indications for fissure sealants.

Consequently, the resin-based control group demonstrated the highest overall SBS, confirming that conventional etch-and-rinse systems remain the gold standard when optimal isolation is achieved. However, the giomer sealant presented a viable alternative with superior bonding performance compared with GICs. The findings suggest that when using giomer sealants, clinicians should prefer phosphoric acid etching over self-etching primers to maximize retention. However, glass ionomer sealants demonstrated lower bond strengths, particularly in no-pretreatment subgroups. This mirrors research by Prabhakar *et al.* [22] (2016) and Gunasekaran *et al.* [23] (2024), supporting the strategic use of GIC in moisture-compromised clinical environments where chemical bonding and fluoride release are prioritized over mechanical retention.

4.3 Bonding failure analysis

The occurrence of cohesive and mixed failure modes across several groups has clinical significance. Adhesive failures were predominant in groups with lower bond strengths, particularly in the glass ionomer groups without pretreatment, indicating that the interface was the weakest link. Conversely, cohesive and mixed failures were more frequent in groups exhibiting higher SBS values. These patterns imply that the bond interface is sufficiently strong to resist immediate detachment.

Clinically, this suggests that even if partial debonding occurs under occlusal stress, residual material may remain within the fissures, potentially continuing to provide a physical barrier or bioactive protection against cariogenic challenges.

4.4 Study limitations

The present study has certain limitations that should be considered. First, the use of flattened enamel surfaces required for standardized shear bond strength testing (ISO 29022) does not reflect the complex geometry of natural fissures or the penetration capability of the sealants. The flat-surface model may have disadvantaged the GIC groups by excluding the penetration and locking factors that are critical to their performance *in vivo* [12, 16].

Second, this study evaluated immediate bond strength without subjecting the specimens to thermal cycling or long-term water ageing. Therefore, the findings represent immediate bond strength data. Future studies incorporating artificial aging are necessary to evaluate the long-term durability of the bond interface against hydrolytic degradation.

In this study, bovine incisors were selected as the substitute due to their availability and histochemical similarity to human enamel [24]. While this facilitates standardization and minimizes variability, future *in vivo* studies and long-term clinical trials are warranted to fully validate the clinical longevity of these materials under dynamic oral conditions.

5. Conclusions

Within the limitations of this *in vitro* study, the resin-based fissure sealant applied with phosphoric acid etching demonstrated the highest SBS values, confirming its status as the gold standard when optimal isolation can be achieved. However, among the bioactive materials, the giomer-based sealant exhibited superior bonding performance compared with the glass ionomer-based sealants.

Notably, phosphoric acid etching significantly enhanced the adhesion of the giomer material compared with its specific self-etching primer. Therefore, if a bioactive giomer sealant is selected, surface pretreatment with phosphoric acid is recommended to maximize retention. While these results provide valuable insights, future *in vivo* studies are warranted to validate the longevity and preventive efficacy of these protocols under dynamic oral conditions.

ABBREVIATIONS

ARI, Adhesive Remnant Index; GIC, Glass Ionomer Cement; GIS, Glass Ionomer Sealant; LED, Light Emitting Diode; MPa, Megapascal; RBS, Resin-Based Sealant; S-PRG, Surface Pre-Reacted Glass; SBS, Shear Bond Strength; SD, Standard Deviation; YULECAE, Yeditepe University Local Ethics Committee for Animal Experiments; ISO, International Organization for Standardization; FT, Fuji TRIAGE; RP, Riva Protect; BT, BeautiSealant; HF, HeliOSEAL F Plus (Control); FTA, Fuji TRIAGE + Acid; FTC, Fuji TRIAGE + Conditioner; FTN, Fuji TRIAGE (No pretreatment); RPA, Riva Protect + Acid; RPC, Riva Protect + Conditioner; RPN, Riva Protect (No pre-

treatment); BSA, BeautiSealant + Acid; BSC, BeautiSealant + Conditioner; BSN, BeautiSealant (No pretreatment); ANOVA, Analysis of Variance.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

BA and SSK—designed the research study; wrote the original draft of the manuscript. BA—performed the research and data collection; analyzed the data. SSK—provided help and advice on the methodology and contributed to editorial changes in the manuscript. Both authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The Yeditepe University Local Ethics Committee reviewed the study protocol for Animal Experiments during the meeting held on 21 May 2024. It was determined that the study was exempt from formal ethical approval requirements, as the research utilized bovine teeth obtained from slaughterhouse waste. This is in accordance with Article 8 of the “Regulation on the Working Procedures and Principles of Animal Experiments Ethics Committees”, which excludes procedures using dead animal tissue or slaughterhouse materials from the scope of ethical review.

ACKNOWLEDGMENT

The authors would like to thank Ayşe Çelik for her valuable contributions during the laboratory phases of the study. We also express our sincere gratitude to Aylin Yaba Uçar for her assistance with the imaging procedures and for providing material support. Finally, we would like to thank İsmehan Ardiç for her technical assistance and for providing access to the necessary laboratory equipment.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest. The authors have no proprietary, financial, professional, or other personal interest of any nature or kind in any product, service, and/or company that could be construed as influencing the position presented in, or the review of, the manuscript.

REFERENCES

- [1] Zhai L, Kong J, Zhao C, Xu Y, Sang X, Zhu W, *et al.* Global trends and challenges in childhood caries: a 20-year bibliometric review. *Translational Pediatrics*. 2025; 14: 139–152.

- [2] Wen PYF, Chen MX, Zhong YJ, Dong QQ, Wong HM. Global burden and inequality of dental caries, 1990 to 2019. *Journal of Dental Research*. 2022; 101: 392–399.
- [3] Rajkumari L, Verma RK, Rajmohan M, Thakkar R, Menon I, Kumar S. Clinical evaluation of the retention of four different pit and fissure sealants on the first permanent molars—an original research. *Journal of Pharmacy & Bioallied Sciences*. 2024; 16: S250–S253.
- [4] Amend S, Boutsiouki C, Winter J, Kloukos D, Frankenberger R, Krämer N. Clinical effectiveness of pit and fissure sealants in primary and permanent teeth of children and adolescents: an umbrella review. *European Archives of Paediatric Dentistry*. 2024; 25: 289–315.
- [5] Prabakar J, Jeevanandan G, Kengadaran S. *In vitro* evaluation of viscosity, depth of penetration, microleakage, and shear bond strength of conventional and hydrophilic sealants. *International Journal of Clinical Pediatric Dentistry*. 2023; 16: 745–750.
- [6] Li N, Nikaido T, Alireza S, Takagaki T, Chen JH, Tagami J. Phosphoric acid-etching promotes bond strength and formation of acid-base resistant zone on enamel. *Operative Dentistry*. 2013; 38: 82–90.
- [7] Rao LN, Sarkar S, Shetty A, Shetty H, Shetty S, Mohamed RN, *et al.* A comparative study of polydopamine vs. glass ionomer cement for adhesion mechanisms on enamel and dentin using SEM and shear bond strength evaluation. *Scientific Reports*. 2025; 15: 2243.
- [8] Suzuki M, Yamada A, Saito K, Hino R, Sugawara Y, Ono M, *et al.* Application of a tooth-surface coating material containing pre-reacted glass-ionomer fillers for caries prevention. *Pediatric Dental Journal*. 2015; 25: 72–78.
- [9] Ogawa Y, Sayed M, Hiraishi N, Al-Haj Husain N, Tagami J, Özcan M, *et al.* Effect of surface pre-reacted glass ionomer containing dental sealant on the inhibition of enamel demineralization. *Journal of Functional Biomaterials*. 2022; 13: 189.
- [10] Meller C, Reichenmiller K, Schwahn C, Samietz S, Blunck U. Resin-based pit-and-fissure sealants: microleakage reduction and infiltration enhancement using a bonding agent. *The Journal of Adhesive Dentistry*. 2015; 17: 59–65.
- [11] Markovic D, Peric T, Petrovic B. Glass-ionomer fissure sealants: clinical observations up to 13 years. *Journal of Dentistry*. 2018; 79: 85–89.
- [12] Ng TC, Chu CH, Yu OY. A concise review of dental sealants in caries management. *Frontiers in Oral Health*. 2023; 4: 1180405.
- [13] Yapar MI, Bayındır YZ. Investigation of shear bond strength of composite resin and glass ionomer cement to dentin with different roughening methods. *Acta Odontologica Turcica*. 2026; 43: 17–24.
- [14] Di Nicoló R, Shintome LK, Myaki SI, Nagayassu MP. Bond strength of resin modified glass ionomer cement to primary dentin after cutting with different bur types and dentin conditioning. *Journal of Applied Oral Science*. 2007; 15: 459–464.
- [15] Zavare D, Merrikk M, Akbari H. Comparison of the shear bond strength in giomer and resin-modified glass ionomer in class V lesions. *Heliyon*. 2023; 9: e14105.
- [16] Miranda C, Prates LHM, Vieira R de S, Calvo MCM. Shear bond strength of different adhesive systems to primary dentin and enamel. *Journal of Clinical Pediatric Dentistry*. 2006; 31: 35–40.
- [17] Kaur N, Srivastava N, Rana V, Kaushik N, Pruthi T, Sirohi A. Retention of resin-based versus glass ionomer pit and fissure sealants in permanent molars: a systematic review of randomized clinical trials. *Journal of Indian Society of Pedodontics and Preventive Dentistry*. 2025; 43: 457–467.
- [18] Abozaid D, Elwakeel E, Mohamed MA, Bahnsawy MA, Eldebawy M, Elraggal A, *et al.* Effects of propolis-modified glass ionomer cement on antimicrobial activity and physico-mechanical properties: a systematic review. *Odontology*. 2026; 114: 468–493.
- [19] Poggio C, Beltrami R, Scribante A, Colombo M, Lombardini M. Effects of dentin surface treatments on shear bond strength of glass-ionomer cements. *Annali di Stomatologia*. 2014; 5: 15–22.
- [20] Sidhu SK, Nicholson JW. A review of glass-ionomer cements for clinical dentistry. *Journal of Functional Biomaterials*. 2016; 7: 16.
- [21] Reynolds IR. A review of direct orthodontic bonding. *British Journal of Orthodontics*. 1975; 2: 171–178.
- [22] Prabhakar AR, Balehosur DV, Basappa N. Comparative evaluation of shear bond strength and fluoride release of conventional glass ionomer

- with 1% ethanolic extract of propolis incorporated glass ionomer cement—*in vitro* study. *Journal of Clinical and Diagnostic Research*. 2016; 10: ZC88–ZC91.
- [23] Gunasekaran R, Sharmin D, Baghkomeh PN, Jaganathan G, Ravindran V. Comparative evaluation of wear strength and compressive strength of two pit and fissure sealants with a nanofilled resin coating: an *in vitro* study. *International Journal of Clinical Pediatric Dentistry*. 2024; 17: 31–35.
- [24] Franchini Pan Martinez L, Ferraz NKL, Lannes ACNL, Rodrigues MC, De Carvalho MF, Zina LG, *et al.* Can bovine tooth replace human tooth in laboratory studies? A systematic review. *Journal of Adhesion Science*

and Technology. 2023; 37: 1279–1298.

How to cite this article: Berkay Akay, Senem Selvi Kuvvetli. Effect of surface pretreatment on the shear bond strength of glass ionomer-based and giomer fissure sealants: an *in vitro* study. *Journal of Clinical Pediatric Dentistry*. 2026; 50(4): 91-102. doi: 10.22514/jocpd.2026.093.